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# Manufacture of Large-Aperture Diffractive Optics and Ultrathin Refractive Optics for High-Power Laser and Space Applications

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# Manufacture of large-aperture diffractive optics and ultrathin refractive optics for high-power laser and space applications

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**Abstract:** We have developed equipment and technology for fabricating submicron pitch, high-efficiency diffraction gratings over meter-scale apertures that are used for pulse compression in ultrafast systems around the world. We have also developed wet-etch figuring (WEF) to generate arbitrary continuous contours on ultrathin glass substrates in a closed loop process. The current and future states of these technologies will be discussed.

**OCIS codes:** (050.0050) Diffraction gratings, (220.0220) Optical fabrication, (140.0140) Laser optics,

## 1. Large-aperture diffraction gratings

LLNL has been fabricating large-aperture submicron pitch diffraction gratings for pulse compression since the mid 1990's, when much of the facilitization and process development was done in support of LLNL's original Petawatt laser [1]. Presently, we are fabricating wet-etched low efficiency sampling gratings at 40 cm square aperture for LLNL's NIF laser [2], as well as supplying large-aperture, gold-overcoated high-efficiency gratings for a variety of internal and external users. Some of the unique capabilities existing at LLNL to do this work include rigorous codes for grating design, meniscus coating systems for precision photoresist application on flat substrates up to 1x2 m wide, three laser interference lithography systems including one with collimating optics 1.1 m in diameter capable of printing 1-m diameter submicron-pitch gratings with 10$^{th}$ wave flatness in diffracted wavefront, vacuum coating systems for application of metal and dielectric layers at 1 m aperture, a reactive ion beam etcher capable of uniformly patterning optics at ~60 cm aperture, and a repertoire of processing techniques for control and tailoring of grating profiles. A detailed description of capabilities can be found on our website [3].

There has been considerable activity recently in the construction of Petawatt-class lasers worldwide. We have provided compressor gratings in the last year to the Institute for Laser Engineering, University of Osaka, Japan, and to Rutherford Appleton Laboratory in the U.K. These optics, based on LLNL's original Petawatt technology, were 94 cm diameter gold-overcoated master gratings, 1480 l/mm and optimized for high efficiency at 1.053 μm at near-Littrow mount. Figure 1 shows a full-aperture diffraction efficiency scan of one of the gratings produced.

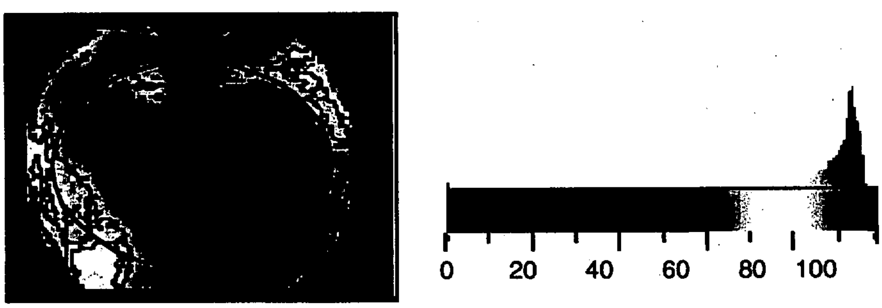


Fig. 1. −1 order % diffraction efficiency (in reflection) of 94 cm diameter, 1480 l/mm grating measured at 1.064 μm, 54° incidence angle. Efficiency 93.8% within beam footprint shown. 80 and 90% efficiency contours also shown.

We are also continuing the development of multilayer dielectric diffraction gratings [4,5]. We have recently fabricated a 355 x 150 mm grating consisting of a 18-layer $Ta_2O_5/SiO_2$ multilayer stack with an ion-beam etched, 1800 l/mm grating in a $SiO_2$ layer, that exhibits >99% diffraction efficiency at the use conditions of 1.030 μm, 64° incidence angle (see Figure 2). This grating is being used in a very high average-power, 4 kHz rep-rate short-pulse machining laser at LLNL. Use of this grating has increased energy throughput at the compressor by 50% compared with the best available gold-overcoated gratings.

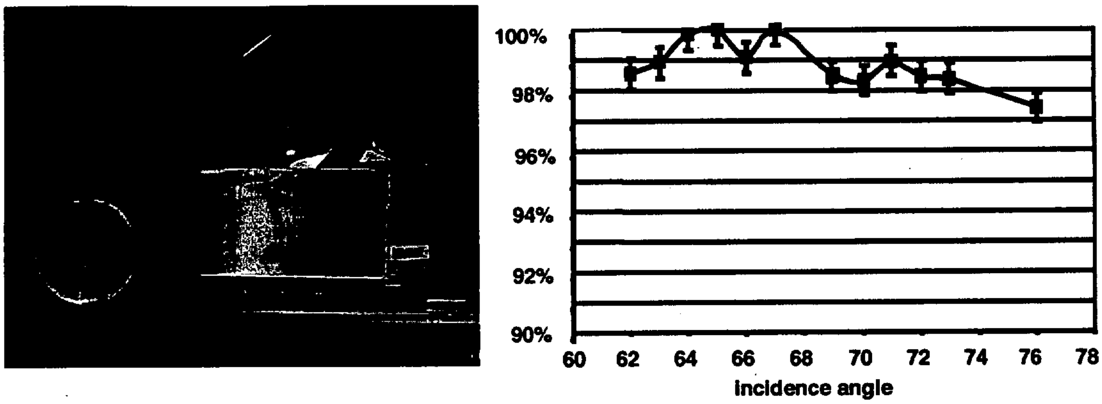


Fig. 2. Left: Photograph of 355x150 mm multilayer dielectric diffraction grating also shown with 150 mm round grating of same design. Right: -1 order diffraction efficiency (in reflection) as function of angle at 1.03 μm for this optic.

Multi-Petawatt laser systems are now on the horizon. Laser damage threshold of the optics will always limit fluence on the optics. The next generation of gratings will be transmission gratings etched into very thin fused silica or high-damage multilayer dielectric gratings, at apertures greater than our current capability. We are in the process of upgrading our ion-beam etching capability to process 2-meter class optics, and also beginning efforts to pattern phased gratings on monolithic substrates in a multi-exposure process.

**2. Wet Etch Figuring**

Minimization of nonlinear self-focusing effects in high-intensity laser systems, and weight constraints of space-deployed optical systems represent compelling reasons to use ultrathin optics whenever feasible. Finishing or figuring of submillimeter thickness optics by conventional means is problematic and very expensive. Inexpensive, thin float or extruded sheet glasses possess excellent specular and microroughness properties as manufactured, but suffer from larger-scale thickness nonuniformities that make this commodity unsuitable for most applications where a precise optical thickness control is required.

We have developed a method for precision optical figuring of ultrathin glass based on confinement of an etchant solution attached to the underside of an optic [6]. A schematic of this geometry is shown Figure 3. Consider a situation wherein aqueous etchant solution issues at a slow rate from the end of a tube facing up, and flows down the outside of the tube. When a glass sheet or other hydrophilic surface is placed near the tube end, capillary forces will attach a liquid droplet to the underside of the glass. If the glass is moved laterally, a thin film of water is left behind the trailing edge of the drop. Introduction of a very small amount of volatile organic carbon (VOC) such as isopropanol vapors in the atmosphere surrounding the drop will result in absorption of this VOC into the liquid film. The concentration of absorbed VOC will be higher in the relatively static zone of the liquid meniscus (labeled A in Fig. 3), than in the region B which is continuously renewed by the falling film flow. This results in a surface tension gradient between A and B sufficiently strong to pull the liquid film off of the surface and confine it to a constant, stable size as the surface is moved laterally with respect to the attached drop. This confinement enables a 'small-tool' figuring process. Simultaneously, the local optic thickness can be measured interferometrically by a laser looking down from above. The local thickness measurements can be used to control the local dwell time of

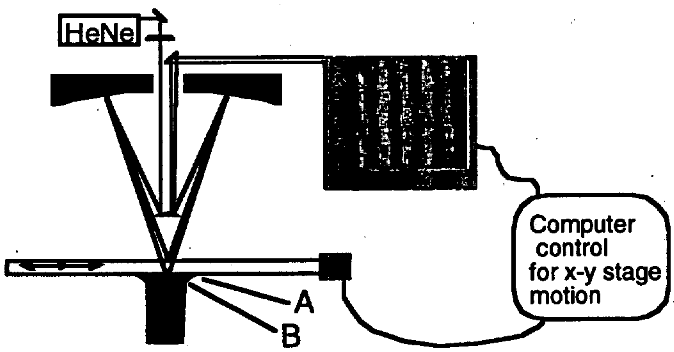


Fig. 3. Schematic of the wet etch figuring (WEF) process

the droplet in a closed loop process using a computer-controlled x-y stage motion to converge on the desired figure with no iteration. This process imparts no mechanical or thermal stresses to the workpiece. It requires only a specular surface to begin with since etching alone cannot reduce microroughness. Figure 4 shows the transmitted wavefront of an optic made using WEF to pre-correct for static aberrations in a large laser system. This optic was figured over a 49 mm aperture on 700 micron-thick extruded sheet glass.

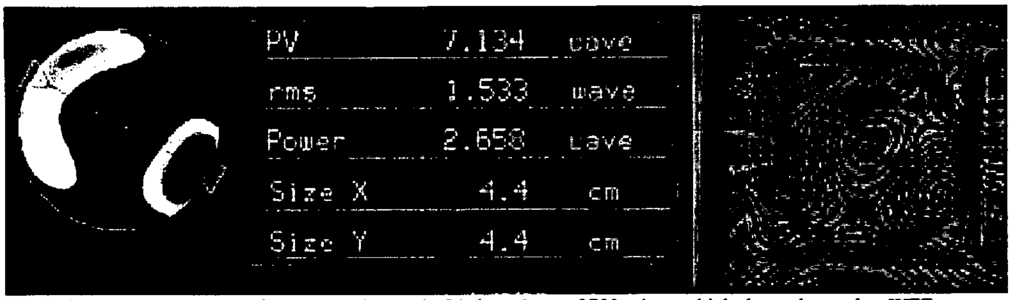


Fig. 4. Transmission interferogram of wavefront correction optic fabricated out of 700 micron-thick sheet glass using WEF.

Commercial extruded thin sheet glass typically exhibits largely one-dimensional thickness variations orthogonal to the draw direction. We have applied the WEF process as a one-dimensional line source to remove the bulk of the thickness variation, leaving a smaller amplitude, larger spatial-scale 2-D residual behind. Figure 5 shows a 150 x 250 mm section of a glass plate flattened by this method. Sheets flattened in this manner have applications as low-cost disposable debris shields for LLNL's NIF laser. Applications requiring flatter glass need to be further figured using a 2-D tool as described above. We have built and currently are using a 1-D WEF tool to flatten 1150 x 850 x 0.7 mm glass sheets for a project whose goal is to deploy a thin segmented Fresnel lens in space [7].

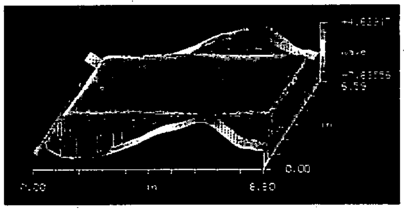

Fig. 5. Transmitted wavefront of a 150x200 mm section of 340 micron-thick borosilicate glass sheet flattened using a 150 mm wide one-dimensional WEF tool. Approximately 9 waves of distortion was removed, leaving about 0.5 waves residual error.

## 3. References

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## 4. Acknowledgements

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